

# CLEO results on non-D $\bar{D}$ decays of $\Psi(3770)$

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for the CLEO collaboration*

## The GAP ... ?

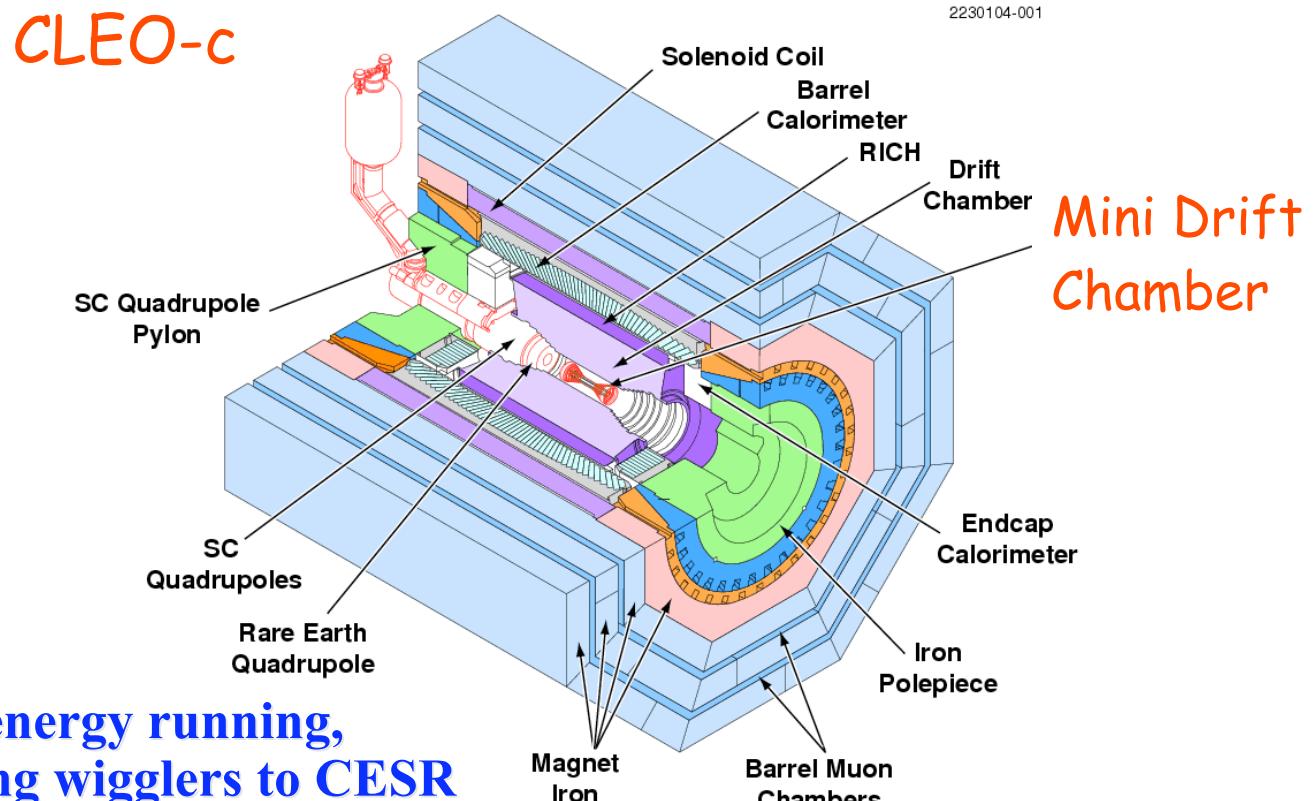
- $\sigma(\psi(3770) \rightarrow D\bar{D} \rightarrow \text{hadrons}) = (6.39 \pm 0.10^{+0.17}_{-0.08}) \text{nb}$   
(PRL 95, 121801 (2005))
- $\sigma(\psi(3770) \rightarrow \text{hadrons}) \sim (7.9 \pm 0.6) \text{ nb}$   
(J. Rosner hep-ph/0411196)
- *Are there significant non- $D\bar{D}$  decays of  $\psi(3770)$  ?*
  - S-D mixing (by how much?)
  - Could some missing modes of  $\psi(2S)$  (e.g.  $\rho\pi$ ) show up in  $\psi(3770)$  decays?

# OUTLINE

- **Observation of  $\psi(3770) \rightarrow \gamma \chi_{c1}$**   
( $281 \text{ pb}^{-1}$ , hep-ex/0509030, submitted to PRL)
- **Observation of  $\psi(3770) \rightarrow X J/\psi$**   
( $281 \text{ pb}^{-1}$ , hep-ex/0508023, submitted to PRL)
- **Search for  $\psi(3770) \rightarrow VP$**   
( $281 \text{ pb}^{-1}$ , hep-ex/0509011, submitted to PRL)
- **Search for  $\psi(3770) \rightarrow \text{multi-body}$**   
( $55.8 \text{ pb}^{-1}$ , hep-ex/0509046, submitted to PRL)
- **Search for  $\psi(3770) \rightarrow K_S K_L$**   
*( $281 \text{ pb}^{-1}$ ) shown for the first time*
- **Measurement of  $\sigma(\psi(3770) \rightarrow \text{hadrons})$**   
*( $281 \text{ pb}^{-1}$ ) shown for the first time*

## CLEO-c Detector/CESR-c Accelerator

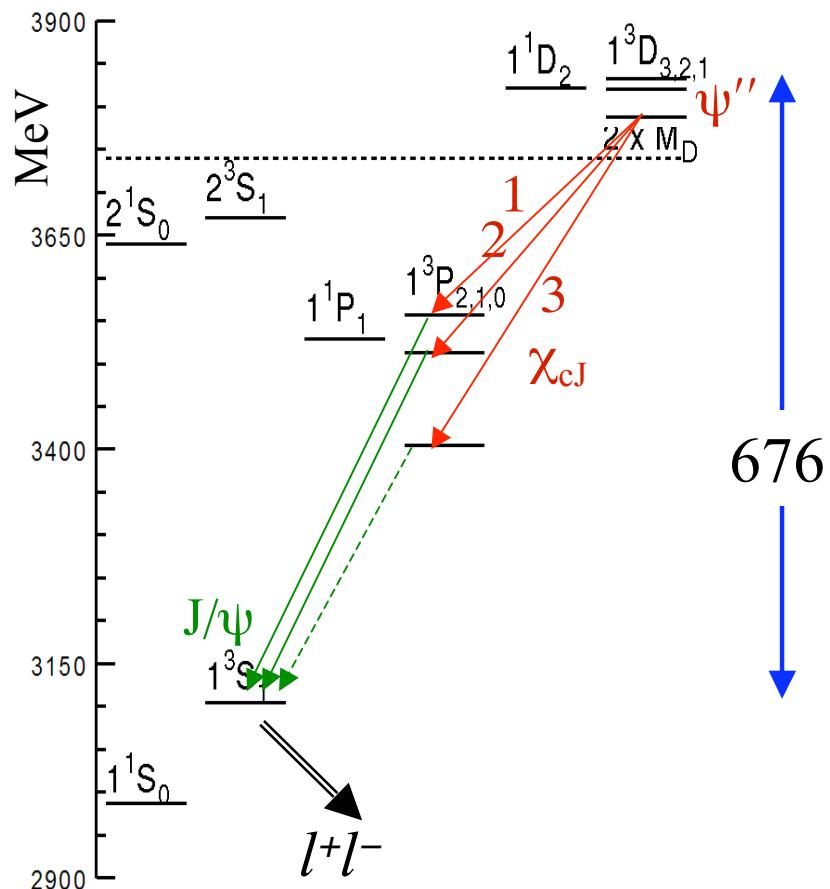
- CLEO3 ( $\gamma$  running)  $\approx$  CLEO-c ( $\psi$  running)



- For these low energy running, superconducting wigglers to CESR needed to be added:
  - Additional damping to compensate for lower synchrotron radiation

# Observation of $\psi(3770) \rightarrow \gamma \chi_{c1}$

- $e^+e^- \rightarrow \psi'' \rightarrow \gamma \chi_{cJ}, \chi_{cJ} \rightarrow \gamma J/\psi, J/\psi \rightarrow l+l-$ 
  - Expected  $E_\gamma$ :
    - $\chi_2 : 211$  MeV (1)
    - $\chi_1 : 253$  MeV (2)
    - $\chi_0 : 341$  MeV (3)
  - $J=0$  state is difficult to observe in two-photon cascades due to its large hadronic width



# Observation of $\psi(3770) \rightarrow \gamma \chi_{c1}$

## Signal:

$\psi(3770) \rightarrow \gamma \chi_{c1} \rightarrow \gamma\gamma J/\psi$   
**with the  $J/\psi \rightarrow e^+e^-$ ,  $l^+l^-$**

## Event selection

**2 photons  $E_\gamma > 60$  MeV**

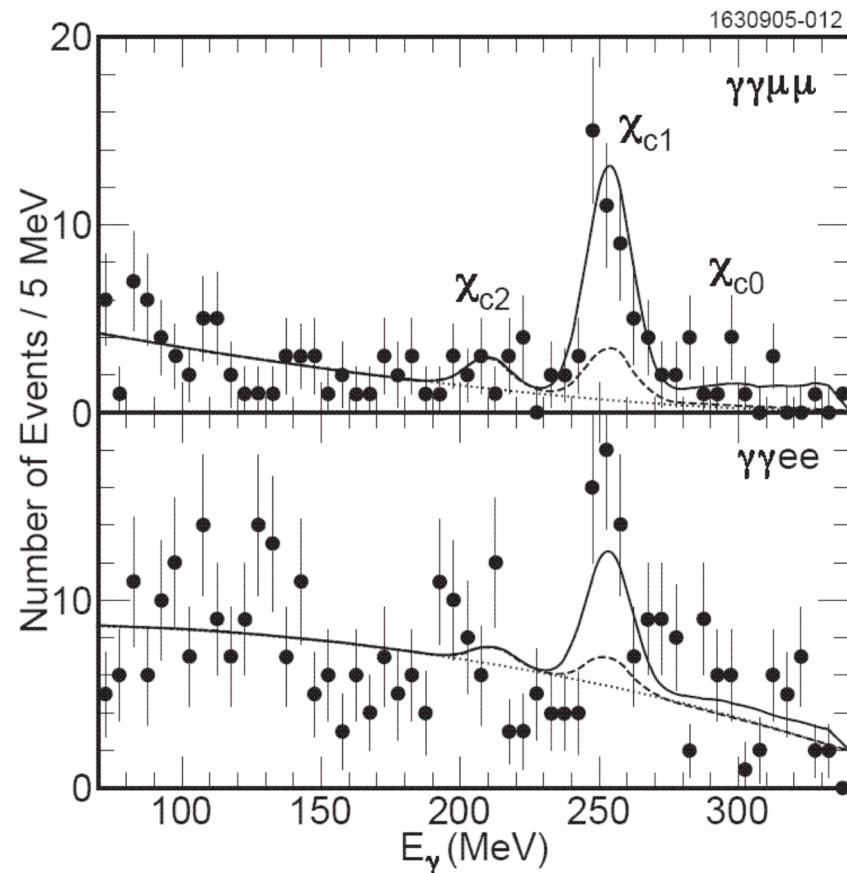
**2 leptons  $P > 1.4$  GeV/c**

**$P_{\text{event}} < 50$  MeV/c**

**$M_{ll}$  within 40 MeV of  $J/\psi$**

**$\pi^0$  and  $\eta$  rejection**

**Kinematic fit the event  
and  $J/\psi$**



**$E_\gamma$  of the lowest energy photon**

## Observation of $\psi(3770) \rightarrow \gamma \chi_{c1}$

We measured:

$$\sigma(e^+e^- \rightarrow \psi(3770)) \times B(\psi(3770) \rightarrow \gamma \chi_{c1})$$

$$= (20.4 \pm 3.7 \pm 2.4) \text{ pb for } \chi_{c1}$$

$$< 10.8 \text{ pb (at 90% C.L.) for } \chi_{c2}$$

$$< 295 \text{ pb (at 90% C.L.) for } \chi_{c0}$$

Also using the measured CLEO cross section

$$\sigma(e^+e^- \rightarrow \psi(3770) \rightarrow D\bar{D}) = (6.4 \pm 0.2) \text{ nb:}$$

$$B(\psi(3770) \rightarrow \gamma \chi_{c1}) = (3.2 \pm 0.6 \pm 0.4) \times 10^{-3}$$

$$B(\psi(3770) \rightarrow \gamma \chi_{c2}) < 1.7 \times 10^{-3} \text{ (90% C.L.)}$$

$$B(\psi(3770) \rightarrow \gamma \chi_{c0}) < 46 \times 10^{-3} \text{ (90% C.L.)}$$

# Observation of $\psi(3770) \rightarrow \gamma \chi_{c1}$

Using the measured decay width of  $\psi(3770)$  (PDG),  
we also extracted:

$$\begin{aligned}\Gamma(\psi(3770) \rightarrow \gamma \chi_{c1}) &= (75 \pm 14 \pm 13) \text{ keV} \\ \Gamma(\psi(3770) \rightarrow \gamma \chi_{c2}) &< 40 \text{ keV (90% C.L.)} \\ \Gamma(\psi(3770) \rightarrow \gamma \chi_{c0}) &< 1.1 \text{ MeV (90% C.L.)}\end{aligned}$$

Using our measured rate for  $\pi^+ \pi^- J/\psi$  we obtain

$$\Gamma(\psi(3770) \rightarrow \gamma \chi_{c1}) / \Gamma(\psi(3770) \rightarrow \pi^+ \pi^- J/\psi) = 1.56 \pm 0.34 \pm 0.25$$

W/  $M(1^3D_2) = 3872 \text{ MeV}/c^2$ , predicted to be:

$$\Gamma(\psi(1^3D_2) \rightarrow \gamma \chi_{c2}) / \Gamma(\psi(1^3D_2) \rightarrow \pi^+ \pi^- J/\psi) = \sim 2.5 - 3 \times 1.56$$

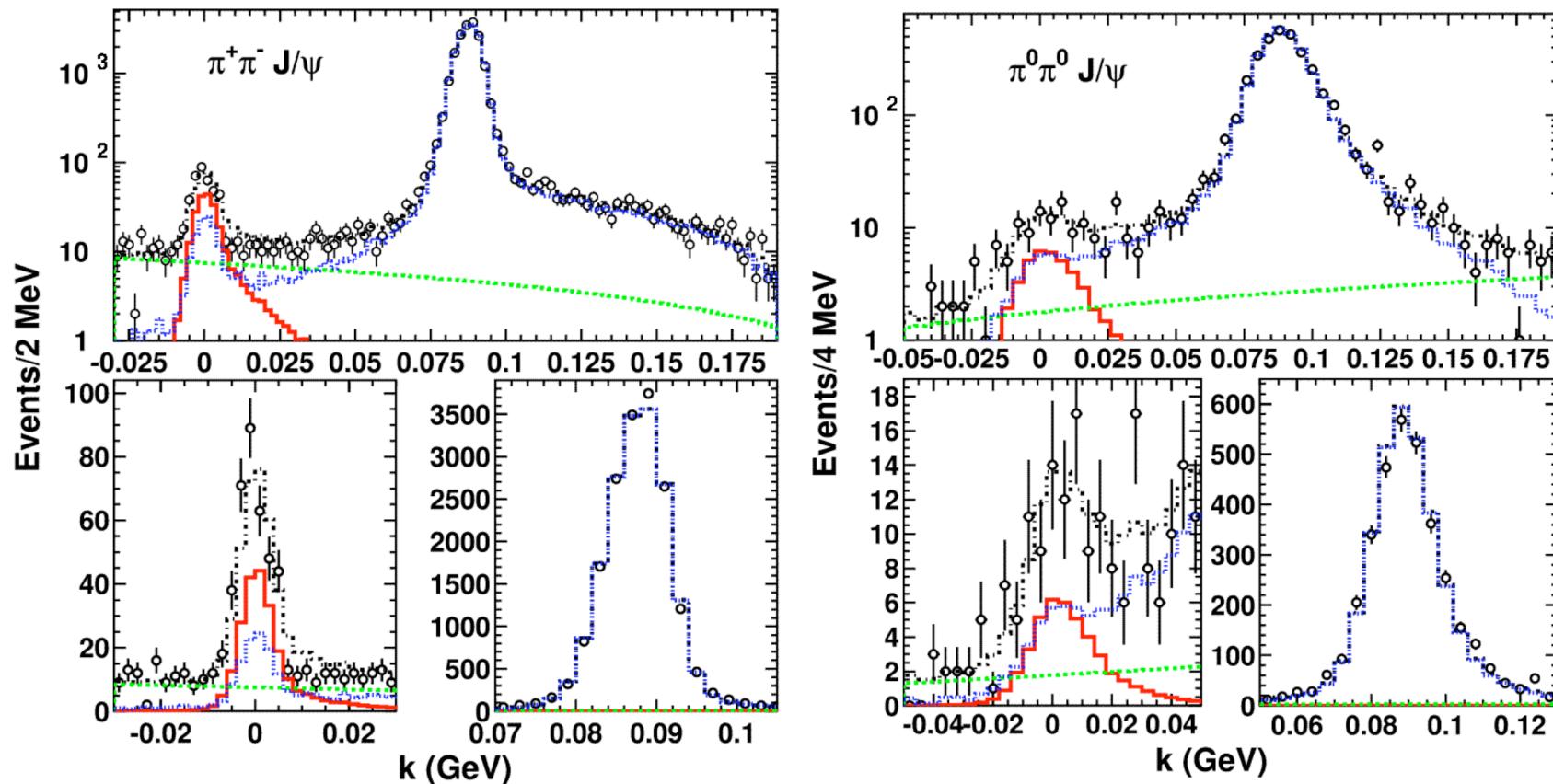
BELL:  $\Gamma(X(3872) \rightarrow \gamma \chi_{c1}) / \Gamma(X(3872) \rightarrow \pi^+ \pi^- J/\psi) < 0.9$  (90% C.L.)

$\rightarrow$  “X(3872) is  $1^3D_2$ ” strongly disfavored.

	$\Gamma(\psi(3770) \rightarrow \gamma \chi_{cJ})$ in keV		
	$J = 2$	$J = 1$	$J = 0$
CLEO data	<40	$75 \pm 18$	< 1100
Rosner (hep-ph/0411003)	$24 \pm 4$	$73 \pm 9$	$523 \pm 12$
Eichten-Lane-Quigg naïve (PRD69, 094019 (2004)) with coupled-channels corrections	3.2 3.9	183 59	254 225
Barnes-Godfrey-Swanson (hep-ph/0505002) non-relativistic potential relativistic potential	4.9 3.3	125 77	403 213

# Observation of $\psi(3770) \rightarrow \pi\pi J/\psi$

**Missing event momentum for  $\pi\pi J/\psi$**



**Red  $\psi(3770)$  direct decay: Blue is radiative return to the  $\psi(2S)$**

# Observation of $\psi(3770) \rightarrow \pi \pi J/\psi$

$X$	$\pi^+ \pi^-$	$\pi^0 \pi^0$	$\eta$	$\pi^0$
$N(\gamma\psi(2S) \rightarrow \gamma X J/\psi)$	$19493 \pm 175 \pm 195$	$3610 \pm 82 \pm 72$	$293 \pm 29 \pm 15$	$< 37$
$\epsilon(\gamma\psi(2S) \rightarrow \gamma X J/\psi)$ (%)	$56.24 \pm 0.07 \pm 0.90$	$21.66 \pm 0.06 \pm 0.65$	$7.87 \pm 0.17 \pm 0.28$	$11.33 \pm 0.12 \pm 0.66$
$\sigma(\gamma\psi(2S) \rightarrow \gamma X J/\psi)$ (pb)	$1036 \pm 14 \pm 23$	$498 \pm 12 \pm 19$	$111.4 \pm 11.2 \pm 7.8$	$< 9.7$
$I(s)$ (pb/keV)	$1448.6 [7.2]$	$1448.6 [7.2]$	$1490.9 [36.7]$	$1447.5 [9.6]$
$\mathcal{B}(\psi(2S) \rightarrow X J/\psi) \times \Gamma_{ee}$ (eV)	$715 \pm 9 \pm 16$	$344 \pm 9 \pm 13$	$74.7 \pm 7.5 \pm 5.2$	$< 6.7$
$\Gamma_{ee}[\psi(2S)]$ (eV)	$2132 \pm 29 \pm 85$	$2082 \pm 55 \pm 108$	$2300 \pm 236 \pm 178$	$< 5171$
$N(\psi(3770) \rightarrow X J/\psi)$	$251 \pm 30 \pm 25$	$45 \pm 16 \pm 9$	$25 \pm 13 \pm 6$	$< 10 @ 90\% \text{ C.L.}$
Significance	$13\sigma$	$3.8\sigma$	$2.2\sigma$	$0\sigma$
$\epsilon(\psi(3770) \rightarrow X J/\psi)$ (%)	$57.37 \pm 0.17 \pm 0.92$	$22.65 \pm 0.17 \pm 0.68$	$11.80 \pm 0.13 \pm 0.42$	$16.16 \pm 0.15 \pm 0.94$
$\sigma(\psi(3770) \rightarrow X J/\psi)$ (pb)	$13.1 \pm 1.5 \pm 1.3$	$5.9 \pm 2.1 \pm 1.2$	$6.4 \pm 3.4 \pm 1.6$	$< 1.9 @ 90\% \text{ C.L.}$
$\mathcal{B}(\psi(3770) \rightarrow X J/\psi)$ ( $10^{-5}$ )	$204 \pm 24 \pm 21$	$92 \pm 34 \pm 19$	$100 \pm 53 \pm 25$	$< 30 @ 90\% \text{ C.L.}$
$\Gamma(\psi(3770) \rightarrow X J/\psi)$ (keV)	$48 \pm 6 \pm 8$	$22 \pm 8 \pm 5$	$24 \pm 13 \pm 7$	$< 7 @ 90\% \text{ C.L.}$

$$\mathcal{B}(\psi(3770) \rightarrow \pi^+ \pi^- J/\psi) = (204 \pm 24 \pm 21) \times 10^{-5}$$

$$\mathcal{B}(\psi(3770) \rightarrow \pi^0 \pi^0 J/\psi) = (92 \pm 34 \pm 19) \times 10^{-5}$$

Add them all  $\rightarrow \sigma(\psi(3770) \rightarrow X J/\psi) < 35 \text{ pb}$

## Search for $\psi(3770) \rightarrow \text{VP, multi-body}$

- $\text{VP} = (\rho \text{ or } \omega \text{ or } \phi) + (\pi \text{ or } \eta \text{ or } \eta'), K^{*0}K^0, K^{*+}K^-, b_1^0\pi^0, b_1^+\pi^-, \text{ also } \pi^+\pi^-\pi^0.$
- **multi-body = combinations of  $\pi, K, p, \eta, \omega, \phi$ .**
- **Energy conservation:  $0.98 < E_{\text{vis}}/E_{\text{cm}} < 1.02$**
- **Momentum conservation:  $|p_{\text{total}}|/E_{\text{cm}} < 0.02$**
- **Compare yields from  $\psi(3770)$  data with the ones from scaled continuum (fully reconstructed events).**

## Search for $\psi(3770) \rightarrow VP$

- For each channel, on- $\psi(3770)$  yields are consistent with continuum prediction except:
- $BR(\psi(3770) \rightarrow \phi\eta) = (3.1 \pm 0.6 \pm 0.3 \pm 0.1) \times 10^{-4}$ .
- $\psi(3770) \rightarrow \pi^+\pi^-\pi^0$ ,  $\rho^0\pi^0$  and  $K^+K^-$  are suppressed.
- Form factors,  $F(s)$ , of  $\omega\pi^0$ ,  $\rho\eta$  and  $\rho\eta'$   
(continuum:  $\sigma(e^+e^- \rightarrow \gamma^* \rightarrow VP) \propto |F(s)|^2$ ) are also obtained:

Channel	$\mathcal{F}(s) (\text{TeV}^{-1})$	
	$\sqrt{s} = 3.671 \text{ GeV}$	$\sqrt{s} = 3.773 \text{ GeV}$
$\omega\pi^0$	$40_{-3}^{+4} \pm 2$	$39 \pm 1 \pm 2$
$\rho\eta$	$34_{-3}^{+4} \pm 2$	$34 \pm 1 \pm 2$
$\rho\eta'$	$17_{-9}^{+14} \pm 1$	$22_{-2}^{+3} \pm 1$

- Add all U.L.'s  $\rightarrow$  no more than 40 pb.

## Search for $\psi(3770) \rightarrow$ multi-body

- multi-body = combinations of  $\pi$ ,  $K$ ,  $p$ ,  $\eta$ ,  $\omega$ ,  $\phi$ .
- Considered 25 different final states, with and without strangeness and/or baryons (see the next).
- Subtract background with scaled continuum data.
- Add all U.L.'s  $\rightarrow$  no more than 200 pb.

# Search for $\psi(3770) \rightarrow$ multi-body

mode	continuum		$f_{co}$	10xD $\bar{D}$ MC		$\psi(3770)$		$N_S$	Sig.	$\varepsilon$	$\sigma$	U.L.	$\mathcal{B}$ U.L.
$h$	$S_{co}$	$B_{co}$		$S_{D\bar{D}}$	$B_{D\bar{D}}$	$S_{\psi(3770)}$	$B_{\psi(3770)}$		(# $\sigma$ )		(pb)	(10 $^{-4}$ )	
$2(\pi^+\pi^-)$	1471	28	2.49	1	13	3411	90	-266.5	-2.5	0.4305	8.7	11.2	
$2(\pi^+\pi^-)\pi^0$	350	18	2.26	15	14	647	18	-120.5	-2.6	0.1990	8.2	10.6	
$\eta\pi^+\pi^-$	15	0	2.57	0	0	41	1	1.5	0.1	0.0450	9.7	12.4	
$\omega\pi^+\pi^-$	43	9	2.35	0	0	107	18	9.1	0.5	0.1638	4.6	6.0	
$\eta 3\pi^a$	27	2	2.61	8	0	67	11	-10.1	-0.6	0.0688	4.5	5.8	
$\eta 3\pi^b$	20	9	2.64	2	1	62	23	9.8	0.6	0.0248	24.0	30.7	
$\eta 3\pi$											10.9	13.4	
$\eta' 3\pi$	1	0	2.75	1	0	5	0	2.2	0.4	0.0149	19.2	24.4	
$K^+K^-\pi^+\pi^-$	954	25	2.40	32	7	2262	47	-16.8	-0.2	0.3720	7.0	9.0	
$\phi\pi^+\pi^-$	33	13	2.43	0	0	77	25	3.3	0.2	0.1629	3.2	4.1	
$\phi f_0$	12	5	2.49	0	2	32	15	-0.2	0.0	0.0863	3.5	4.5	
$K^+K^-\pi^+\pi^-\pi^0$	634	18	1.73	30	21	1121	32	24.9	0.5	0.1283	18.4	23.6	
$\eta K^+K^-$	3	0	2.50	0	0	3	0	-4.5	-0.7	0.0389	3.2	4.1	
$\omega K^+K^-$	62	12	2.31	0	1	114	14	-15.3	-0.7	0.1269	2.6	3.4	
$2(K^+K^-)$	100	11	2.67	9	1	267	7	21.7	0.7	0.3170	4.6	6.0	
$\phi K^+K^-$	46	15	2.59	4	0	118	22	15.2	0.7	0.1564	5.9	7.5	
$2(K^+K^-)\pi^0$	20	0	2.88	8	0	50	0	-8.4	-0.6	0.1479	2.2	2.9	
$p\bar{p}\pi^+\pi^-$	337	28	2.47	0	0	851	60	28.6	0.5	0.5149	4.5	5.8	
$p\bar{p}\pi^+\pi^-\pi^0$	204	9	2.58	0	0	604	16	85.4	2.1	0.2259	14.4	18.5	
$\eta p\bar{p}$	2	1	2.62	0	0	4	2	-0.6	-0.1	0.0469	4.2	5.4	
$\omega p\bar{p}$	26	4	2.58	0	0	54	5	-7.8	-0.5	0.1421	2.2	2.9	
$p\bar{p}K^+K^-$	25	1	2.62	0	0	89	3	23.0	1.5	0.4111	2.5	3.2	
$\phi p\bar{p}$	2	3	2.69	0	0	2	2	0.0	0.0	0.1872	1.1	1.3	
$\Lambda\bar{\Lambda}$	4	1	2.69	0	0	6	0	-2.1	-0.3	0.2154	1.0	1.2	
$\Lambda\bar{\Lambda}\pi^+\pi^-$	23	4	2.37	0	0	42	7	-10.0	-0.7	0.1019	2.0	2.5	
$\Lambda\bar{p}K^+$	65	7	2.57	0	0	150	11	-10.0	-0.4	0.2602	2.2	2.8	
$\Lambda\bar{p}K^+\pi^+\pi^-$	29	3	2.64	0	0	94	17	8.2	0.4	0.1471	4.9	6.3	

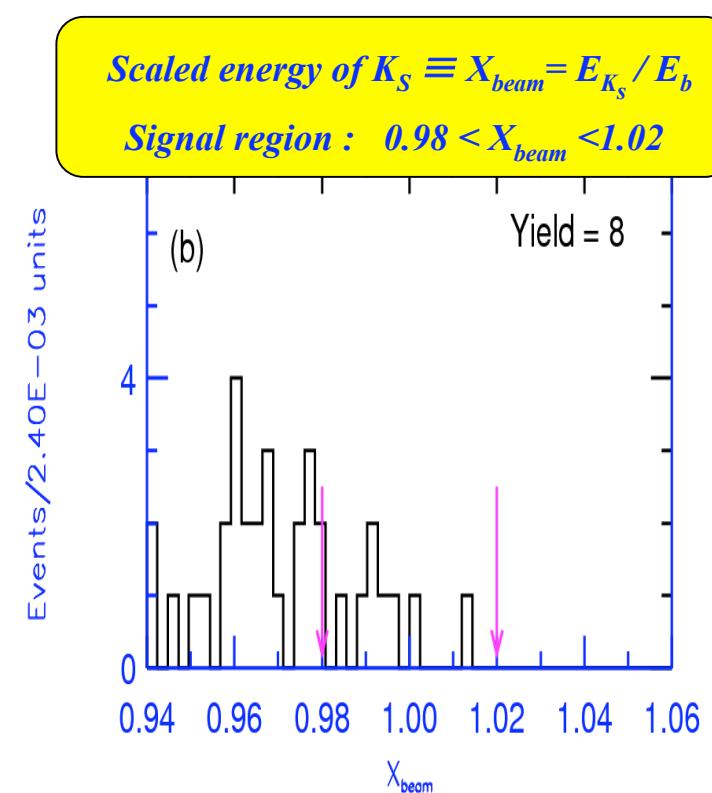
## Search for $\psi(3770) \rightarrow K_S K_L$

- Motivated by the observation of  $\psi(2S) \rightarrow K_S K_L$  (see Guangshun Huang's talk)
- Wang ,Yuan ,Mo [hep-ph/0410300,hep-ph/0402227] (S-D mixing) predict;  
 $(0.12 \pm 0.7) \times 10^{-5} < B(\psi(3770) \rightarrow K_S K_L) < (3.8 \pm 1.1) \times 10^{-5}$

- Reconstruct a  $K_S \rightarrow \pi^+ \pi^-$  candidate in the event,
- Ask for nothing other than a possible  $K_L$  signature on the other side.
- Require events with exactly 2 tracks with displaced vertex.

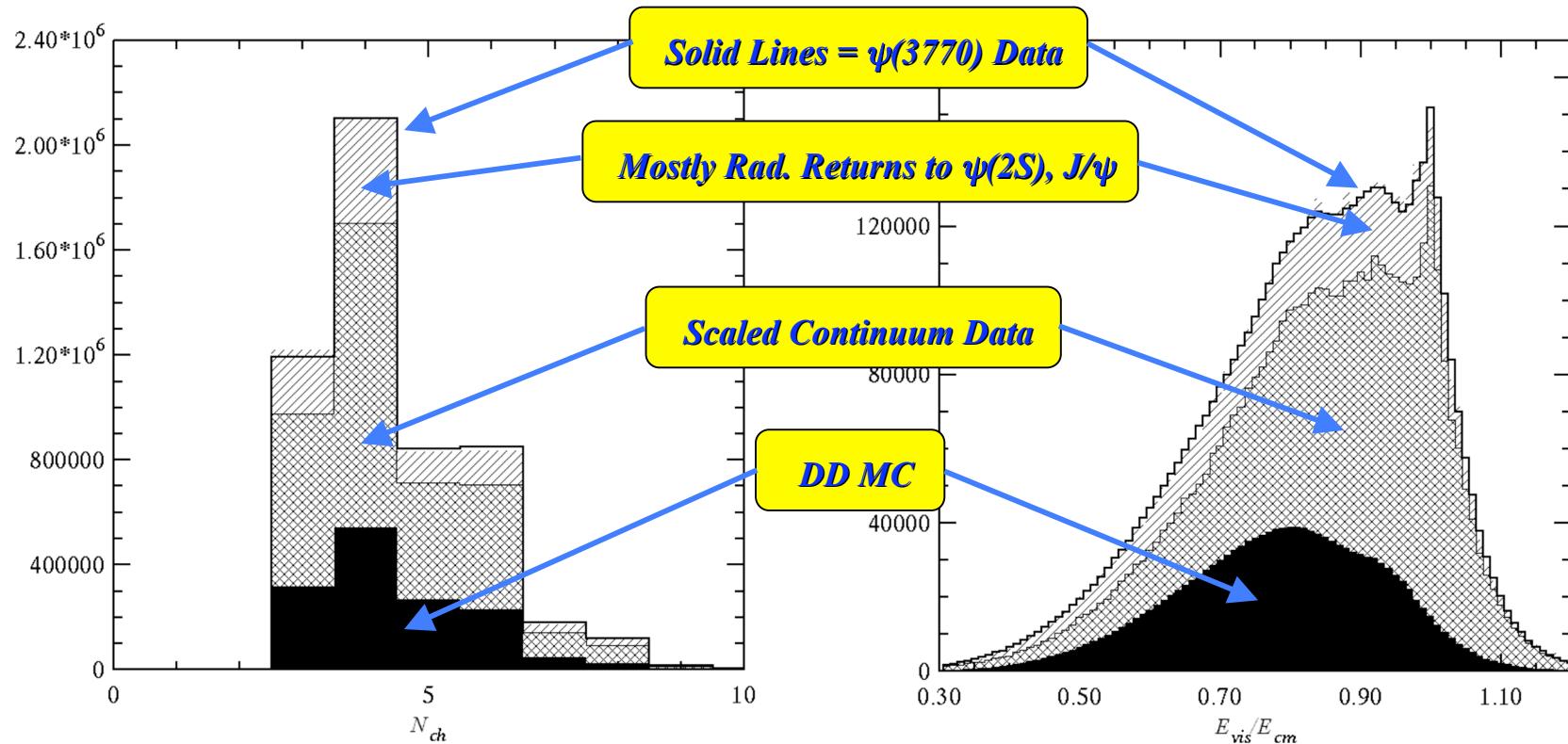
*Preliminary*

Set **upper limit @ 90% C.L.**  
 $\mathcal{O}(\psi'' \rightarrow K_S K_L) < 0.07 \text{ pb}$   
 $B(\psi(3770) \rightarrow K_S K_L) < 1.09 \times 10^{-5}$   
 $< 21 \times 10^{-5}$  : BES (PRD70, 077101 (2004))



# Measurement of $\sigma(\psi(3770) \rightarrow \text{hadrons})$

- Count number of hadrons,  $N_{\text{had}}$ , in data taken at  $E_{\text{cm}}=3.77\text{GeV}$  ( $281\text{ pb}^{-1}$ ).  
Main selection criteria are:
  - # of tracks,  $N_{\text{ch}} \geq 3$
  - total (visible) energy,  $E_{\text{vis}} \geq 0.3 \times E_{\text{cm}}$
- Use continuum data taken at  $E_{\text{cm}}=3.61\text{GeV}$  ( $21\text{ pb}^{-1}$ ) to subtract backgrounds.  
Radiative returns to  $\psi(2S)$  and to  $J/\psi$  are also subtracted.



## Measurement of $\sigma(\psi(3770) \rightarrow \text{hadrons})$

- $\sigma(\psi(3770) \rightarrow \text{hadrons}) = N_{\text{had}} / (\epsilon_{\psi(3770)} \cdot f_{\psi(3770)})$   
where  $\epsilon_{\psi(3770)} = (\epsilon_{\text{DD}} \cdot \sigma_{\text{DD}} + \epsilon_{\text{non-DD}} \cdot \sigma_{\text{non-DD}}) / (\sigma_{\text{DD}} + \sigma_{\text{non-DD}})$ .
- Since  $\sigma_{\psi(3770)} = \sigma_{\text{DD}} + \sigma_{\text{non-DD}}$ , we have;

$$\sigma_{\psi(3770)} = \sigma_{\text{DD}} + (N_{\text{had}} / f_{\psi(3770)} - \epsilon_{\text{DD}} \cdot \sigma_{\text{DD}}) / \epsilon_{\text{non-DD}}$$

- Assumed  $\epsilon_{\text{non-DD}} = (\sigma_{\text{DD}} + \sigma_{\psi(2S)}) / 2$ .
- Used  $\sigma_{\text{DD}} = 6.39 \text{ nb}$ .

Preliminary

$$\sigma(\psi(3770) \rightarrow \text{hadrons}) = [6.5 \pm 0.1^{+0.4}_{-0.3}] \text{ nb at } E_{\text{cm}} = 3.773 \text{ GeV.}$$

- With the reported  $\sigma(\psi(3770) \rightarrow D\bar{D} \rightarrow \text{hadrons})$ ,  
the difference between the two < 0.8 nb @ 90% C.L.

## Summary

- First observation of  $\psi(3770) \rightarrow \gamma \chi_{c1}$ 
    - Observed rates are consistent with theoretical predictions.
    - $\sigma(e^+e^- \rightarrow \psi(3770)) \times B(\psi(3770) \rightarrow \gamma \chi_{c1}) = (20.4 \pm 3.7 \pm 2.4) \text{ pb for } \chi_{c1}$   
 $< 10.8 \text{ pb (at 90\% C.L.) for } \chi_{c2}$   
 $< 295 \text{ pb (at 90\% C.L.) for } \chi_{c0}$
  - Observation of  $\psi(3770) \rightarrow X J/\psi$ 
    - Statistically significant signals are observed ( $13\sigma$  for  $\pi^+\pi^-$  mode).  
 $B(\psi(3770) \rightarrow \pi^+\pi^- J/\psi) = (204 \pm 24 \pm 21) \times 10^{-5}$
    - $\sigma(\psi(3770) \rightarrow X J/\psi) < 35 \text{ pb}$
  - No significant signals were found in  $\psi(3770) \rightarrow$  non  $D\bar{D}$  final states (VP, multi-body,  $K_S K_L$ )
    - $\sigma(\psi(3770) \rightarrow \text{VP, multi-body, } K_S K_L) < 240 \text{ pb}$
  - Measurement on  $\sigma(\psi(3770) \rightarrow \text{hadrons})$ 
    - $\sigma(\psi(3770) \rightarrow \text{hadrons}) = [6.5 \pm 0.1^{+0.4}_{-0.3}] \text{ nb at } E_{\text{cm}} = 3.773 \text{ GeV.}$
    - With the reported  $\sigma(\psi(3770) \rightarrow D\bar{D} \rightarrow \text{hadrons})$ ,  
the difference between the two  $< 0.8 \text{ nb @ 90\% C.L.}$   
(or  $\Gamma_{\text{total}}(\psi(3770)) \cdot (0.8 \text{ nb} / 6.5 \text{ nb}) = 2.9 \text{ MeV}$ )
- Preliminary